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DEVELOPMENT OF AN OPTICAL DISC RECORDER

QUARTERLY TECHNICAL REPORT

1 October 1975 to 31 December 1975

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- disc

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The mechanical parts of the recorder were designed and are in the first stages of assembly. The servo electronics were designed and fabricated. A coding study is under way for the design of the record/playback signal processing electronics. An optical system using HeNe lasers for recording and playback has been proposed; a report on this system is given in Appendix A. A study of possible materials for the disc substrate shows that plexiglas (PMMA) would be a good choice. Several mechanisms have been considered for protecting the recording from dust, fingerprints, and scratches. A program for investigating suitable DRAW recording materials has begun.

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QUARTERLY TECHNICAL REPORT
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1. INTRODUCTORY SUMMARY

The mechanical parts of the recorder were designed and are in the first stages of assembly. The servo electronics were designed and fabricated. A coding study is under way; this is necessary for the design of the record/playback signal processing electronics. An optical system using HeNe lasers for recording and playback has been proposed; a report describing this system is given in Appendix A. A study of possible materials for the disc substrate shows that plexiglas (PMMA) would be a good choice. Several mechanisms have been considered for protecting the recording from dust, fingerprints, and scratches. A program for investigating suitable DRAW recording materials has begun.

2. DISCUSSION

2.1 Recorder Mechanical System

The recorder mechanical parts were designed and are in the early stages of assembly. This first phase has been carried out by Philips Research Laboratories in the Netherlands. Figure 1 shows the basic configuration of the recorder. Two critical bearings for the optical sled and the lens focusing system are of the air bearing design. The choice of air bearings for the sled was partly determined by the need for random track access. The problems and considerations for the recorder are similar to those of Contract No. DAAB03-74-C-0368.

2.2 Recorder Electronics

The servo electronics for lens focusing, motor speed control, and sled drive motor were fabricated and bench tested. Final testing must await completion of mechanical assembly.

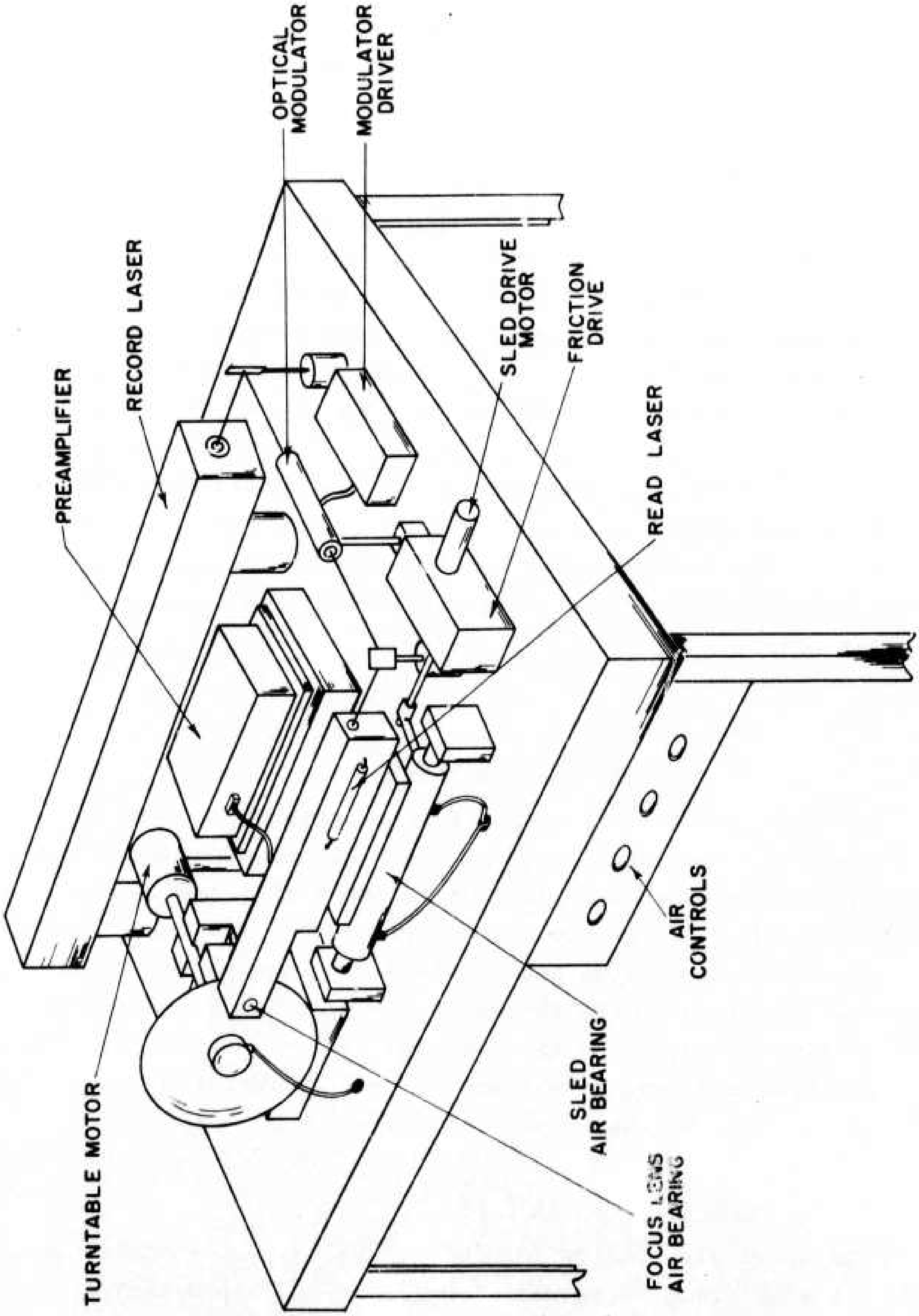

Figure 1: Optical disc recorder concept.

A study to determine the optimum coding configuration and error correcting techniques is being conducted by Philips Research Laboratories in the Netherlands. Disc characterization and optimum equalization techniques are also under study there. Preliminary indications are that a type of run-length-limited code would give high transmission efficiency, be self clocking, and not require a DC channel response. A 4/5 run-length-limited code which maps 4 data bits into 5 recorded bits is now being considered. Run-length-limited coding is also known as group-coded-recording or G.C.R. Hamming cyclic coding is one of the error-correction techniques under study.

The design of the record/playback electronics must await the completion of the coding, equalization, and error correction study.

2.3 Recorder Optics

A survey of lasers suitable for recording reveals only two possibilities, viz., HeNe (λ = 6328 Å) and HeCd (λ = 4416 Å). A HeNe 20 mW laser is available at $1000 from several sources, including Spectra Physics. The HeNe laser has excellent reliability and a lifetime in excess of 10,000 hours. Since there is a developing market for this laser (i.e., IBM 3800 laser printer), its supply is reasonably assured.

A 20 mW HeCd laser is available from Liconix for $1200. The expected lifetime is 5000 hours. Though the noise and reliability of HeCd lasers are historically worse than HeNe lasers, the shorter wavelength means more materials can be considered for recording. However, our first choice is still the HeNe laser.

For playback, the least expensive source is a 1 mW HeNe laser of the type used in the Philips-MCA video disc player. However, careful consideration must be given to separating the read beam from the recording beam. A 1000:1 rejection of the recording beam at the read photodiode is required. The MCA, Philips, and other video disc recorders use an HeNe laser for reading, but

use shorter wavelengths for recording. The two wavelengths can be easily separated by dichroic filtering. The problem of single-wavelength record/playback beam separation may be solved by specifying polarization and angular differences between the record and read beams. The proposed system is described in Appendix A.

An acoustic-optic modulator will be used for recording. This type of modulator offers several advantages over electro-optic modulators, viz., price and transmission efficiency. Datalight and Coherent Associates offer similar A-O modulators with 96% transmission in the zero order mode and 15:1 extension ratios. Coherent Associates has quoted a price of $350.00 in quantities of 1000 units. Modulators from Datalight and Coherent Associates were tested; a Coherent Associates modulator Model 304D was ordered.

An Olympus NA = 0.75 microscope objective lens was procured and tested. The Airy disc spot diameter was found to be 1 μm for for $\lambda = 6328$ Å. This indicates near diffraction-limited performance by the lens. The experimental setup and procedure is given in Appendix B.

2.4 Disc Substrates and Protective Mechanisms

A study of disc substrates reveals plexiglas or polymethyl methacrylate (PMMA) would be a good choice. PMMA is normally cast between two polished plates and therefore has excellent local surface roughness and low defects. The gross flatness characteristics and long term stability of PMMA is also good. PMMA is also clear and free of bi-refringence. The price per disc substrate will be about $2.00. Glassflex, Inc., Stirling, N.J., has produced satisfactory samples of PMMA discs; a small quantity of discs has been ordered.

Another substrate being considered is hot-pressed PVC, which is less expensive than PMMA but not as stable.

Two apparatus were constructed for measuring disc irregularities, viz., disc unflatness and track out-of-roundness or eccentricity. These measurements will be useful in evaluating the overall record/playback performance of the disc.

Several mechanisms have been considered to protect the recording from dust, fingerprints, and scratches. The three best candidates are the "air cover foil", "the contact sandwich", and the "air sandwich". The "air cover foil" (see Fig. 2) consists of an air-supported foil flying above the disc information surface. The foil is supported by a gas flow (clean air or nitrogen) through several holes lying on a circle. The foil protects the information surface when the disc is rotating. At rest, the foil adheres to the disc due to electrostatic forces. The air cover foil was successfully demonstrated at Philips Research Laboratories, the Netherlands.

The "contact sandwich" method (Fig. 3) uses a laminate of 180 μm glass and a plastic substrate with the information layer in the middle. The plastic substrate protects the glass from breakage. The glass layer will not be deformed by heat during recording and will remain transparent for reading. Thin glass from Corning was procured. Initial tests of the contact sandwich indicate a degradation of writing sensitivity, probably due to additional heat loss to the glass layer. The results are presented in Appendix C.

The "air sandwich" shown in Figure 4 consists of two discs each coated with an information-sensitive layer, separated by ring gaskets at the inner and outer radii. The potential advantages of this configuration are: protection of the information layers without degrading writing sensitivity, containment of the vapors produced during writing, and a two-sided disc. The air sandwich concept, now in the initial stage of testing, appears to be the most attractive method for protecting the disc.

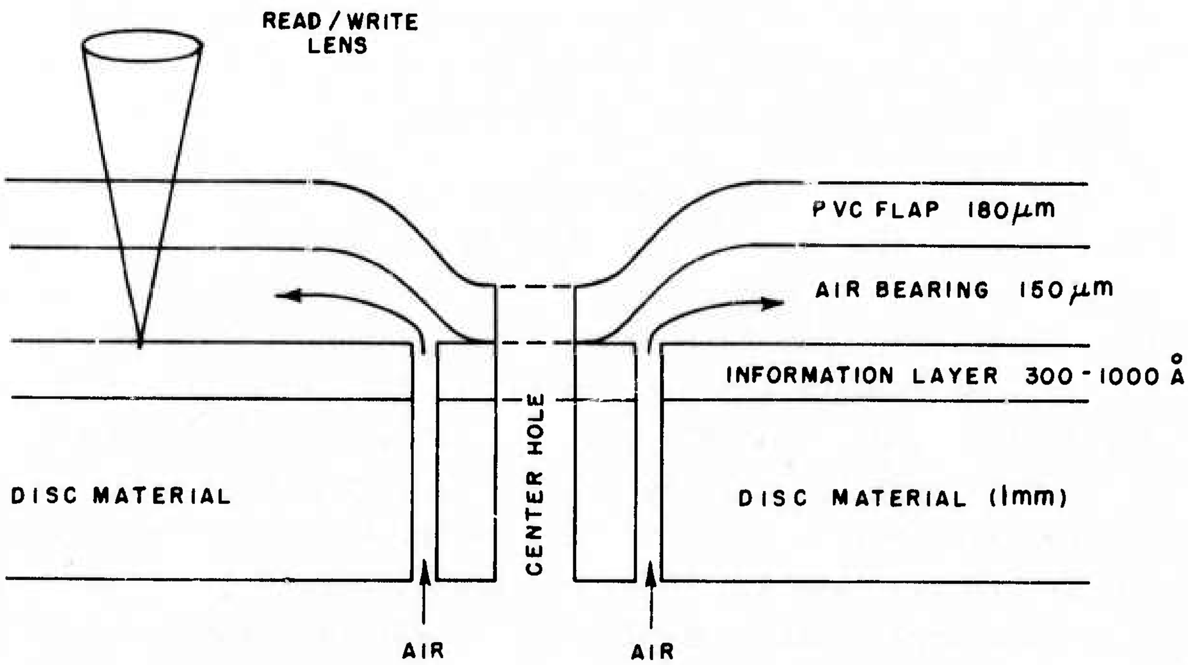

Figure 2: "Air cover foil".

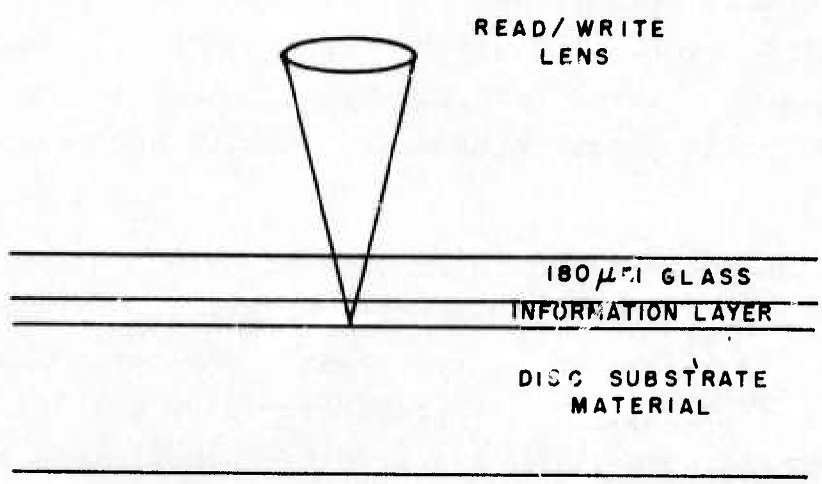

Figure 3: Contact sandwich.

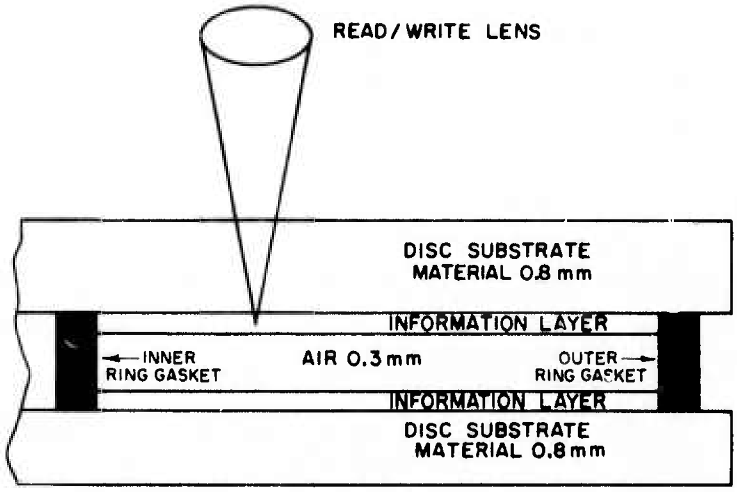

Figure 4: Air sandwich protective configuration.

2.5 DRAW Recording Materials

Preliminary survey studies are in progress for several of the candidate materials mentioned in the proposal. Results to date are as follows:

Bismuth Oxide. The best films produced show sensitivities to irradiation by 50 nsec laser pulses, 488 nm, of about 225 mJ/cm^2 for 1300 Å thick films. Absorption is roughly independent of wavelength from 488 nm to 633 nm. The sensitivity obtained appears to be inadequate for the proposed system.

Arsenic Selenide. We have conducted several experiments investigating various approaches for containing the vaporization products of AsSe laser machining. The results suggest that both the air-sandwich and the contact sandwich structures have possibilities. The contact sandwich shows, for 1.0 μsec pulses, about 30% loss in sensitivity compared to that of non-protected films. However, it was also observed that a rather severe degradation in sensitivity, roughly linearly proportional to pulse duration, occurs on increasing the pulse duration from 0.2 μsec to 1.0 μsec. This leads to a sensitivity of about 600 mJ/cm^2 for 6 μm holes with 1.0 μsec exposures. These experiments suggest that $AsSe_3$ may not be sensitive enough for the proposed system.

As a result of these experiments and discussions with various researchers at Philips Research Laboratories in the Netherlands, at Briarcliff Manor, and at Bell Laboratories, the following has been decided:

(1) Bismuth

Bismuth continues to be an attractive candidate and will be investigated in detail both here and in the Netherlands. Dr. Zalm and de Bont at the Netherland Laboratories have fabricated 300 Å bismuth film discs which shows excellent signal-to-noise ratios for analog recording. The use of a 300 Å thick bismuth film instead of the 500 Å thickness mentioned in the proposal should yield improvements in sensitivity at the expense of shelf life.

(2) Low Boiling Point Materials

Fundamental investigations at Bell Laboratories suggest that the boiling point is the material characteristic that determines the sensitivity for several materials. We plan, therefore, to investigate the low boiling point materials, Sb and Se.

3. PLANS

(a) Continue assembly of recorder.

(b) Continue coding study.

(c) Assemble optical subsystem.

(d) Complete testing of air-sandwich protective mechanism.

(e) Complete construction and testing of disc unflatness and out-of-roundness measuring apparatus.

(f) Continue investigation of DRAW materials.

APPENDIX A

Optics For Optical Disc Recorder

PHILIPS LABORATORIES

OPTICS FOR OPTICAL DISC RECORDER

by T. Demetrakopoulos

The schematic shown in Figure 1 indicates the optical setup for the direct-read-after-write (DRAW) optical disc recorder. The optical system employes two lasers of the same wavelength, such as a 20 mW HeNe laser for writing and an inexpensive 1 mW HeNe laser for reading.

Briefly, the system operates as follows: The writing beam is modulated and then expanded by the spot lens to fill up the objective. The half-wave plate rotates the polarization of the writing beam so that the writing and reading beams are polarized at 90°.

The reading part of the DRAW recorder is similar to that of the VLP® video disc player. After passing through the grating, the read beam is split into the various diffraction orders; however, only the 0, +1 and -1 orders are used. The grating is such that about 82% of the energy is concentrated almost equally among these three orders. The +1 and -1 diffraction orders are used for tracking, and the zero order for focusing and information reading. The spot lens is used for filling up the objective. The tangential mirror can be used for timebase error correction; the radial mirror is used for radial tracking.

A focusing method similar to that used in the VLP®* player is planned. The diodes provide the information, tracking, and focusing signals. The radial mirror movement and the objective focusing servo are controlled by the tracking and focusing signals, respectively.

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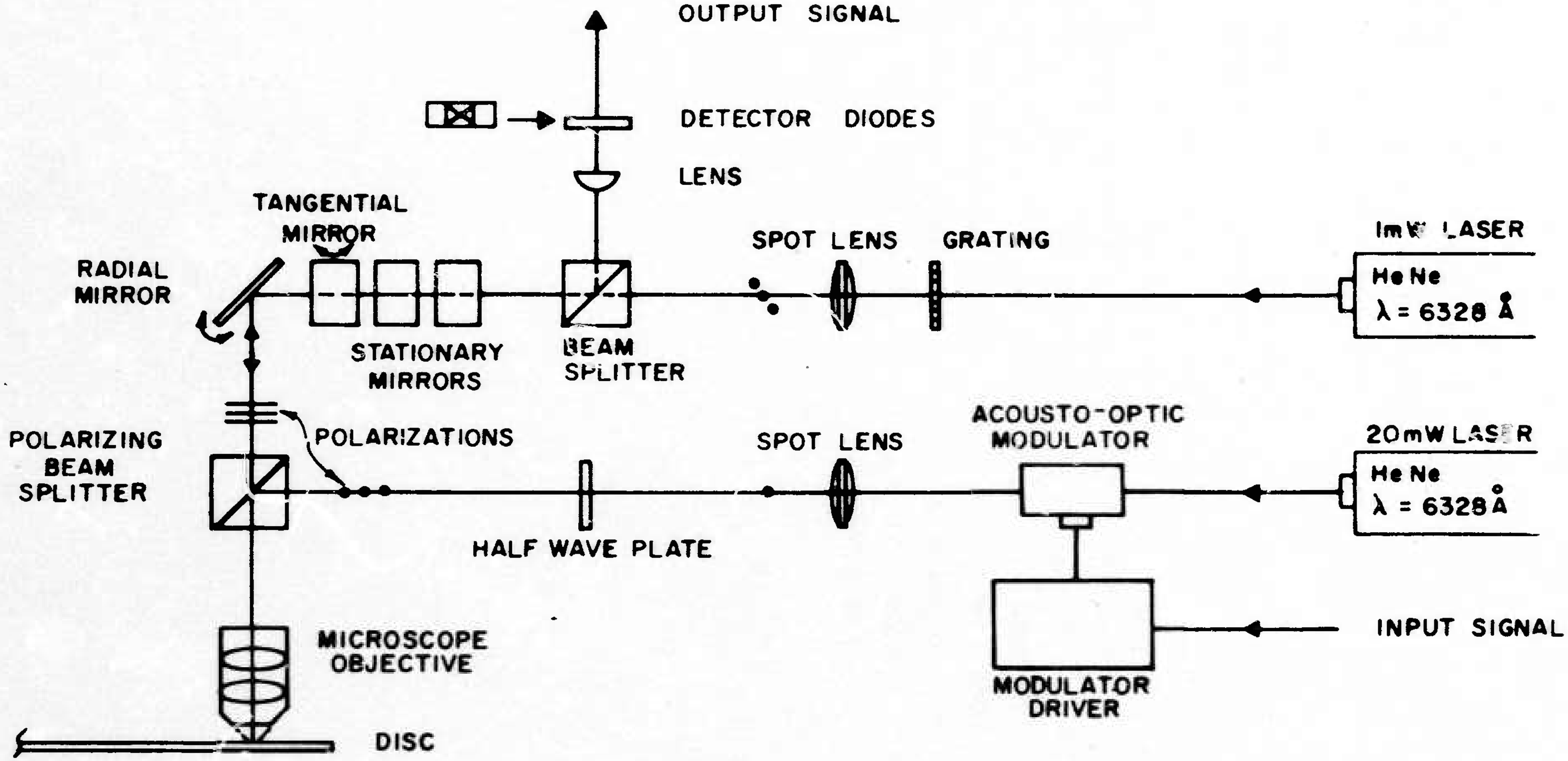

Figure 1: Schematic for direct-read-after-write optical disc recorder using same wavelength lasers for reading and writing.

The separation between the reading and writing reflected beams is accomplished by: angular separation, and a 90° polarization between the reading and writing beams. The reading and writing beams form an angle θ, as seen in Figure 2. Thus, the reflected light from the writing beam will not interfere with the tracking and reading beams. Moreover, due to the 90° polarization between the two beams, only depolarized light from the writing beam will be reflected to the detectors. A preliminary measurement shows that only about 1/1000 of the light entering the writing spot lens was reflected to the detectors. This measurement was performed by using a mirror in front of the objective, thus providing about 96% reflection. It is assumed that, in the real case, the reflection of the writing beam from the disc will be considerably smaller than 96%, and thus the effect of the reflected writing beam in the detectors will be less noticeable.

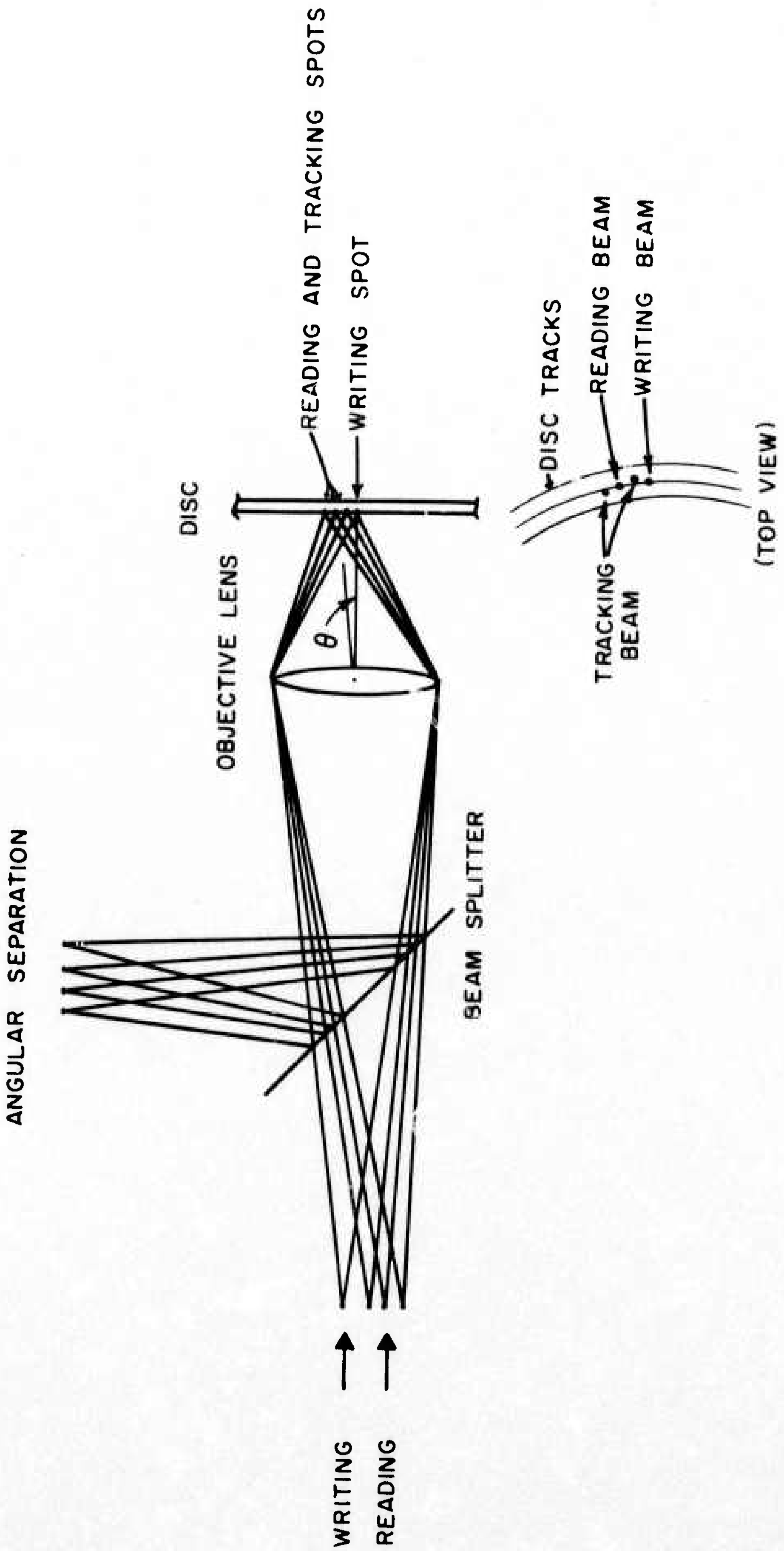

Figure 2: Simplified diagram showing the angular separation between the reading and writing beams.

APPENDIX B

Spot Size Measurement of Microscope Objective

SPOT SIZE MEASUREMENT OF MICROSCOPE OBJECTIVE

by T. Demetrakopoulos

The microscope objective for the DRAW optical disc recorder was purchased. It is an OLYMPUS objective with a N.A. = 0.75 and a magnification factor of 40X.

The spot size* of the objective was measured using the projection microscope technique (see Fig. 1). Objective MO_1 is the OLYMPUS objective whose spot size is projected on the screen with a projection microscope. Objective MO_2 is a Zeiss Epiplan with a N.A. = 0.95 and a magnification of 80X. The numerical aperture of MO_2 is higher than that of MO_1 so that maximum collection of the focused cone of light occurs. The alignment of the system is very critical, since misalignment causes distortions on the energy distribution.

The magnification of the projection microscope is calculated as follows. A mask consisting of 7 μm diameter transparent holes on an opaque background and spaced 19 μm apart from each other is inserted in front of MO_2 (with MO_1 removed). Then, the image of the mask is projected and focused on the screen. Dividing the spacing between the bright spots on the screen by the distance between the holes of the mask, we find a magnification factor of $M \approx 2263$. Then, the microscope objective MO_1 is inserted and its spot size is focused on the screen. Figure 2 shows the magnified Airy disk pattern of the focused spot. The spot size is obtained by dividing the diameter of the central Airy disk by the magnification $M = 2263$. The Airy disk dark-ring diameter was found $D_{spot} = 1$ μm for $\lambda = 6328$ Å. Spot diameter to $1/e^2$ points is $0.86\ \mu m \approx \frac{\lambda}{N.A.}$

The incident light distribution on MO_1 was such that the ratio of the beam waist (w) [measured between the $1/e^2$ points] to the lens aperture radius (a) was $w/a \approx 1.12$. Under such

* The spot size is defined to be the diameter of the central maximum of the Airy intensity distribution.

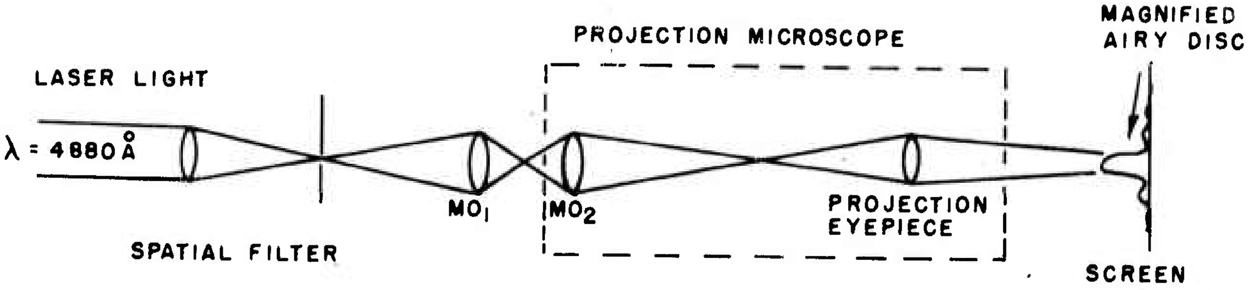

Figure 1: Optical setup for measuring spot size of microscope objective MO_1.

Figure 2: Magnified Airy pattern as seen on screen. (not to scale)

conditions, i.e., lens is overfilled, the diameter of the spot size is about equal to the Airy disc diameter.[1] Theoretically, the Airy disk diameter can be estimated from the well known formula[2] $D_{spot} = \frac{1.22\lambda}{N.A.}$, provided that the incident wave is a plane wave. Substituting for $\lambda = 6328$ Å and N.A. = 0.75, we find $D_{spot} \approx 1.03$.

Thus, the estimated theoretical value of the spot size and the one measured are reasonably close considering the approximations of the measurements. It can be seen that by decreasing the lens aperture, the spot size increased, as predicted.

Theoretically, the central spot and first ring of the Airy pattern at best focus have 84% and 7.2% of the energy distribution[3]. In our case, 79% and 8.3% of the power were measured in the first maximum and first ring, respectively, which indicates that the lens is nearly diffraction-limited.

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APPENDIX C

Effect of Protective Contact Coating on Static Sensitivity of Arsenic Selenide Films to Laser Micromachining

EFFECT OF PROTECTIVE CONTACT COATING ON STATIC SENSITIVITY OF ARSENIC SELENIDE FILMS TO LASER MICROMACHINING

by David Lou

Arsenic selenide ($As_{27}Se_{73} \approx AsSe_3$) has been demonstrated to be an attractive medium for direct-read-after-write (DRAW) recording by laser micromachining. However, since the laser machining process involves evaporation of the film material, and since the vaporization products of AsSe are toxic, some means must be found to contain the vaporization products. One possible approach is a "sandwich" structure, shown in Figure 1, in which a protective coating is applied over the AsSe film. This report gives the preliminary results of measurements on the static sensitivity of sandwiched AsSe films.

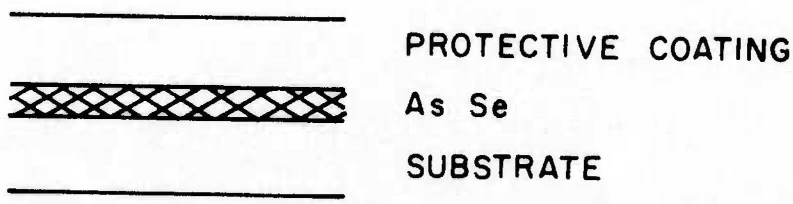

FIG. I

Intuitively, one would expect a degradation in sensitivity because of the increased heat loss due to the presence of an additional conductive material in contact with the AsSe film, and because in a completely confined sandwich structure, AsSe must reach a higher temperature in order to boil or retract. In fact, preliminary experiments at Philips Research Laboratories in the Netherlands have shown that AsSe films sandwiched with Loctite (Fig. 2) barely reach threshold at power levels that produce micron-size holes in unsandwiched films, indicating a factor of two to three loss in sensitivity. Thus, at Briarcliff Manor, we have concentrated our investigations in structures where

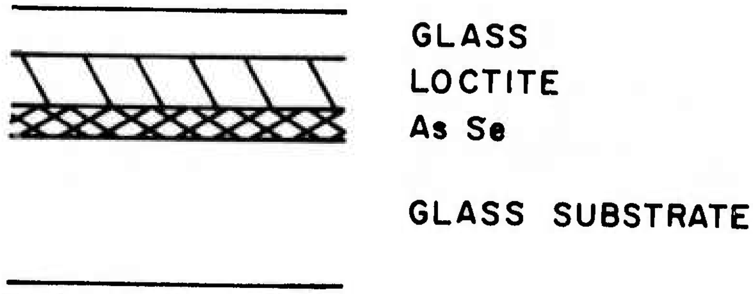

FIG. 2

a layer of material, easily damageable by laser irradiation, is inserted into the basic sandwich structure in contact with the AsSe film. Under laser irradiation, bubbles form in this intermediate layer thereby freeing the AsSe film surface and reducing the deleterious effects of the protective sandwich.

Figure 3 shows schematic diagrams of the structures we have evaluated. Samples of 600 Å AsSe films on glass substrates were obtained from the Laboratories in the Netherlands (Fig. 3A). This was the control sample. Poly-isobutyl-methacrylate was used as the intermediate layer material, and applied by spin-coating from a solution of Elvacite 2045 resin in xylene. The thickness of the coating was determined to be 20 μm by weight measurement assuming a density of 1 gm/cm^3 (Fig. 3B). Corning Microglas, 175 μm thick, was bonded to coated samples with Eastman 910 adhesive (Fig. 3C). These samples were then machined with a 488 nm argon laser beam incident from the coating side. Incident laser power was 91 mW at the surface of the film. Beam diameter was 6 μm. The diameters of the machined holes were then measured optically with a microscope, both in reflection and in transmission. The coatings on the 3B samples were then removed by spraying with acetone, and the hole sizes measured again (Fig. 3D). The results are listed in Table I, under the columns A, B, C, D, respectively. Structure D is probably the most attractive from the point of view of handling.

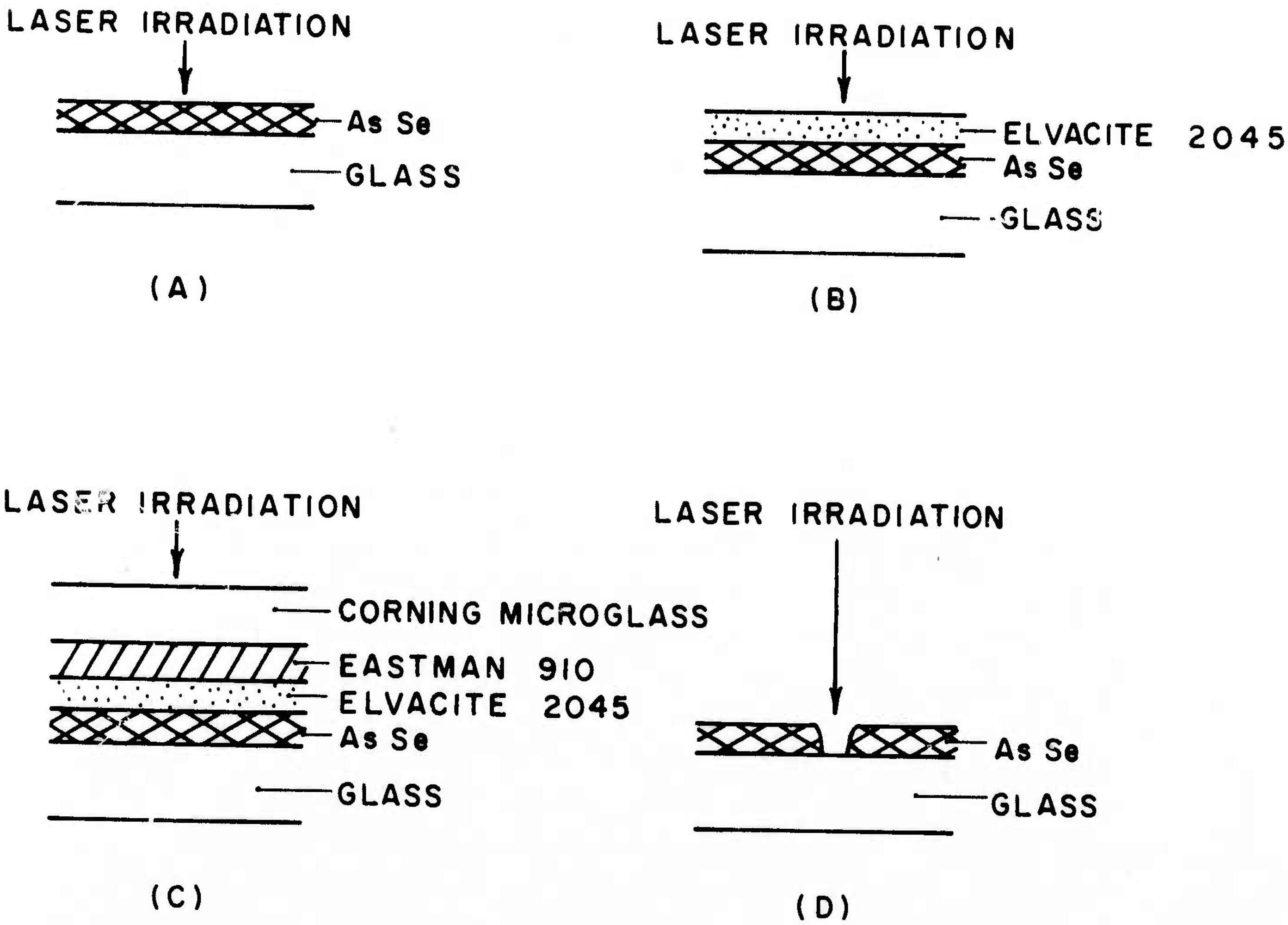

FIG. 3

Several comments are worthy of note here:

(1) For the coated sandwich, it was impractical to measure hole sizes by the scanning electron microscope. To be able to measure the hole sizes optically, we used a 6 μm diameter beam instead of the 1 μm beam which would be used in DRAW recording. Straightforward scaling of the results from 6 μm to 1 μm may well be dangerous.

(2) Sensitivity is generally defined at the point where the hole size is equal to the beam size of the laser. The sensitivities listed in Table I are values extrapolated from measured sensitivities according to the formula:

$$S(r_o) = S(r) \left(\frac{r}{r_o}\right)^2 \exp\left(1 - \frac{r^2}{r_o^2}\right)$$

where,

r = hole radius

r_o = beam radius

$S(r)$ = sensitivity measured at 4r

$S(r_o)$ = sensitivity at r_o

Strictly speaking, this formula is valid only when the size of the hole formed is determined solely by the energy density distribution in the laser beam, so that:

$$r^2 = r_o^2 \frac{\ln E(r)}{\ln E(r_o)}$$

where, $E(r)$ = pulse energy required to form a hole of radius r.

(3) In the measurements under the optical microscope, reflection measures the size of the bubbles formed in the intermediate layer, while transmission measures the size of the holes formed in the AsSe film.

(4) Bubbles in the intermediate layer show higher apparent sensitivity than holes in the bare film. The measured hole size also seems to be reasonably reproducible from sample to sample. It may be attractive to store digital information in the bubbles.

(5) It was very difficult to choose the right focus for transmissive hole-size measurements of the coated films, as evidenced by the wide scatter in the measured data. Furthermore, there was a large discrepancy in measured hole size on transmission and reflection, even after the coating had been removed. This suggests a hole profile as shown in Figure 4, and indicates that there may be serious problems in reading analog signals out of the film itself, either by transmission or reflection from the coating side.

(6) The data in Table I indicates that in the worst case, that of transmissive readout for 1.0 μsec pulses, there is a loss in

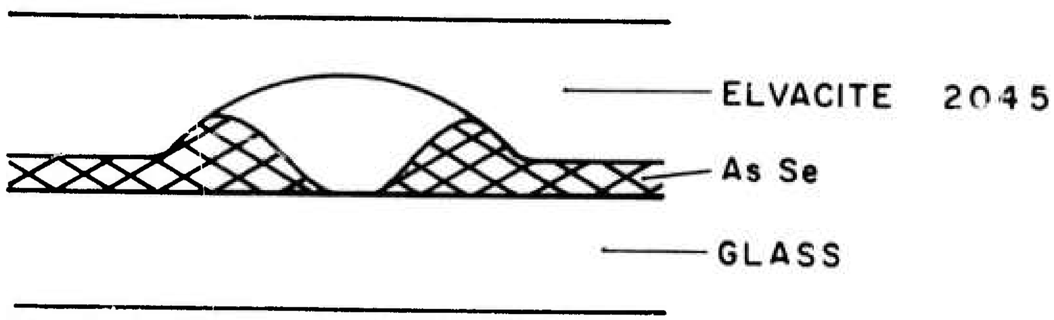

FIG. 4

sensitivity of about 15% when the AsSe film is overcoated with 20 μm of poly-isobutyl-methacrylate in the form of Elvacite 2045, and a further loss of another 10% when the coating is sealed in by a solid glass layer. The total loss of 27% gives an acceptable sensitivity and does suggest possibilities of using the sandwich structure to contain the vaporization products from AsSe machining. It is, however, appropriate here to repeat the caveats introduced earlier. The experiments were carried out with a 6 μm diameter laser beam producing holes 3 μm in diameter, with 1.0 μsec duration pulses. These experimental conditions are quite different from the realities of DRAW recording, where one would be using a 1 μm diameter beam to produce a 1 μm diameter hole with pulse durations of from 50 nsec to 500 nsec. Furthermore, for analog recording, the laser irradiation would probably have to be incident from the uncoated side of the AsSe film.

The conclusions drawn from the data of Table I should, therefore, be regarded merely as suggestive of the possibilities of the sandwich structure in the containment of AsSe. Further experiments are necessary for definitive results.

I would like to acknowledge helpful discussions with Dr. Zalm and Mr. R. deBont of Philips Research Laboratories in the Netherlands and with Mr. C. Balas and Mr. G. Kenney of Philips Laboratories. Mr. E. Lindale assisted in fabrication of the sandwiches, and Dr. Demetrakopoulos in the evaluation.

TABLE I

HOLE DIAMETERS AND SENSITIVITIES OF SANDWICHED ARSENIC SELENIDE FILMS

Incident Laser Power at Film Surface = 91 mW
Laser Beam Diameter = 6 μm

D = Measured Hole Diameter in μm
S = Sensitivity in mJ/cm^2, extrapolated to hole diameter = 6μm

Pulse Duration \ Structure	A: Glass		B: 2045 Overcoat		C: Microglas Epoxied to 2045 Overcoat		D: 2045 Overcoat, Removed	
Reflective Readout	D	S	D	S	D	S	D	S
1.0 μsec	3.7	598	4.6	486	4.5	498	4.3	523
	3.9	573	4.6	486			4.6	486
0.5 μsec	3.3	323	4.0	280	3.7	299	4.0	280
	3.5	311	4.0	280			4.0	280
0.2 μsec	2.6	145	3.0	137			2.7	143
Transmissive Readout	D	S	D	S	D	S	D	S
1.0 μsec	3.7	598	2.8	705	2.2	766	3.4	636
	3.9	573	3.4	636			3.6	612
0.5 μsec	3.7	299	2.4	324	1.6	408	3.1	336
	3.5	311	2.8	353			2.6	363
0.2 μsec	2.6	145	1.3	167			2.2	153